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## Description

### Background of the Invention

#### Field of the Invention

The present invention relates to a method of synthesizing crystals of cubic system boron nitride (referred to hereinafter as cBN). Particularly, it relates to a method of synthesizing a large number of crystals of cBN at a time by using a synthesizing vessel divided into a plurality of chambers.

#### Description of the Prior Art

Methods of synthesizing cBN are generally classified as two methods. According to one of them, hexagonal system boron nitride (referred to hereinafter as hBN) is used as the starting raw material and this material is mixed with or brought into contact with a solvent such as an alkaline metal, an alkaline earth metal, or a nitride thereof or a boronitride thereof to be subjected to cBN-stable ultra-high pressure and high temperature whereby hBN is converted to cBN under the action of the solvent.

According to this method, the solvent penetrates into the starting raw material hBN, whereby boron nitride (referred to hereinbefore as BN) is diffused through the solvent in the form of a thin film to generate cBN. The driving force for generation of cBN in this method is difference between solubility of hBN and that of cBN with respect to the solvent under a constant temperature. In this method, cBN is spontaneously nucleated and is rapidly grown until it reaches a certain size. A large quantity of fine powder of cBN is synthesized by this method. However, crystals having a large size and good quality cannot be synthesized by the above described method.

Another method for synthesizing crystals of cBN is described for example in Japanese Patent Laying-Open Gazette No. 156399/1982, in which large-sized crystals of cBN of high quality can be synthesized. This method utilizes a synthesizing vessel as shown in Fig. 2. Referring to Fig. 2, a seed crystal 1 is placed in a portion near the lower end of the synthesizing vessel surrounded by molybdenum plates 5. A BN source 2 is provided in a central portion along the axial direction of the synthesizing vessel and a solvent 3 is placed under the BN source 2. The portions outside the molybdenum plates 5 are filled with a pressure transmitting medium. A cylindrical heater 4 is disposed around the synthesizing vessel so that the synthesizing vessel is heated by the heater 4.

In the synthesizing vessel shown in Fig. 2, the central portion in the axial direction of the vessel is heated to the highest temperature and the upper and lower ends of the vessel are heated at relatively low temperatures. BN dissolved in the solvent 3 from the BN sources 2 under the ultra-high pressure and high temperature conditions for maintaining cBN stable is deposited as cBN on the seed crystal having a relatively low temperature. This method makes use of a difference in solubility

of BN to the solvent metal due to a temperature difference and is called a temperature difference method. Advantages of the temperature difference method are that cBN can be grown only from the seed crystal and that the growth rate can be controlled by maintaining a temperature difference at a prescribed value. According to the above described temperature difference method, it is ascertained in laboratory scale that large-sized cBN of 0.5 ct. (carat) size can be synthesized.

In this temperature difference method, an arrangement symmetrical with regard to a horizontal center line, including an upper chamber and a lower chamber having BN sources 2, solvents 3 and seed crystals oppositely as shown in Fig. 3 may be adopted so that the space in the synthesizing vessel can be effectively used. This arrangement in the synthesizing vessel has a temperature distribution symmetrical (schematically shown on the right of Fig. 3) with regard to the horizontal center line, having a high temperature in the central portion in the axial direction of the vessel and decreasing temperatures toward the upper and lower ends of the vessel. However, as the result of conducting experiments by actually using such a synthesizing vessel, it is made clear that large-sized crystals of cBN of good quality can be synthesized in the lower chamber of the vessel, while crystals of good quality cannot be grown in the upper chamber of the vessel even if temperature of the upper chamber is maintained at the same as one of the lower chamber and the same materials are used. The reason for this are considered to be as follows. When hBN is dissolved in the solvent, the specific gravity of the solvent is decreased. The specific gravity also decreases as the temperature increases. In the lower chamber of the vessel, solution of hBN in the solvent occurs in an upper end of the solvent and the temperature is raised higher in the upper end. On the other hand, solution of hBN and increase of the temperature in the upper chamber of the vessel occur in a reversed manner. Thus, the lower end of the solvent in the upper chamber of the vessel has the smallest specific gravity and convection occurs in the upper chamber by the influence of the gravity. As a result, BN is excessively supplied to the upper end portion where seed crystals are placed, which makes it impossible to control the growth rate for growing crystals of good quality.

From the above described reasons, cBN can be synthesized only in the lower chamber of the synthesizing vessel by the conventional synthesizing method based on the temperature difference.

#### Summary of the Invention

According to the technique of synthesizing cBN by the above described conventional temperature difference method, the space in the synthesizing vessel could not be effectively utilized as described above.

Therefore, an object of the present invention is

to provide a method of synthesizing efficiently large-sized crystals of cBN of high quality.

The present invention has been accomplished by noticing the following two points.

(1) A plurality of solvents having different eutectic temperatures with respect to hBN are used according to the respective temperatures in synthesizing chambers and BN sources and seed crystals associated with the respective solvents are used. By selecting the solvents, the BN sources and the seed crystals in the above described manner, cBN can be synthesized in each of the appropriately divided chambers of the synthesizing vessel having a certain temperature distribution.

(2) The synthesizing vessel is heated with a specified temperature gradient. In combination with the method indicated in (1), each of the chambers divided as multiple stages is heated with a temperature gradient in which an end portion of each chamber is heated at a relatively high temperature and the other end portion of each chamber is heated at a relatively low temperature. Thus, the whole space of the synthesizing vessel can be effectively utilized.

More specifically stated, the present invention is a method of synthesizing crystals of cubic system boron nitride by using boron nitride sources, solvents for dissolving the boron nitride sources and seed crystals under conditions of ultra-high pressure and high temperature where cubic system boron nitride can be maintained stable. This method uses a synthesizing vessel divided into two or more chambers separated by one or more partition layers not reacting with the solvents, the synthesizing vessel being constructed so that the two or more chambers are disposed to be heated with a temperature gradient in a specified direction. The above stated method of the present invention comprises the steps of: placing, in the two or more chambers, the above stated solvents having different eutectic temperatures with respect to the boron nitride sources according to the above stated gradient; placing the boron nitride sources in contact with portions of the solvents heated at relatively higher temperatures at the time of high-temperature heat treatment; placing at least one seed crystal in a portion of each solvent heated at a relatively lower temperature at the time of the high-temperature heat treatment; and growing at least one crystal of cubic system boron nitride in each of the solvents in the chambers by applying the heat treatment to the synthesizing vessel under conditions of ultra-high pressure and high temperature to give the above stated temperature gradient to the synthesizing vessel.

These objects and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

#### Brief Description of the Drawings

Fig. 1 is a sectional view showing a synthesizing vessel to be used for applying a synthesizing method of an embodiment of the present invention.

Fig. 2 is a sectional view showing a synthesizing vessel used in a conventional temperature difference method.

Fig. 3 is a sectional view showing a synthesizing vessel used in another conventional synthesizing method.

Fig. 4 is a graph for explaining the principle of the present invention, showing pressure and temperature regions where crystals of cBN can be synthesized.

Fig. 5 is a sectional view showing another example of a synthesizing vessel used in an embodiment of the present invention, the synthesizing vessel being composed of four chambers.

Fig. 6A is a sectional view for explaining an example of a heater used for heating a synthesizing vessel in which a method of the present invention is embodied.

Fig. 6B is a sectional view showing another example of a heater used for heating a synthesizing vessel in which a method of the present invention is embodied.

#### Description of the Preferred Embodiments

Fig. 1 is a sectional view showing an example of a synthesizing vessel used in the present invention. In this example, a synthesizing vessel enclosed with a molybdenum material 15 is disposed in a cylindrical heater 14 and this synthesizing vessel is divided into two chambers 10a and 10b. BN sources 12a and 12b, solvents 13a and 13b and seed crystals 11a and 11b are placed in the chambers 10a and 10b, respectively, in the same direction. The seed crystals 11a and 11b are embedded in seed beds 16 and 16b, respectively. The seed bed 16a separates the chambers 10a and 10b and therefore it functions as a partition layer in this invention.

If synthesizing vessel shown in Fig. 1 is heated by using a heater 14, a temperature gradient obtained is as shown on the right of Fig. 1. If cBN is synthesized in the synthesizing vessel shown in Fig. 1, there are caused temperature differences  $\Delta T_1$  and  $\Delta T_2$  in the seed crystals of the chambers 10a and 10b, respectively, between the upper end portion and the lower end portion of the solvents 13a and 13b. Needless to say, the temperature ranges of these chambers are different.

Fig. 4 shows an equilibrium line KK' between cBN and hBN and change in eutectic temperatures of the utilized solvents with respect to hBN. A range where cBN can be synthesized is a pressure and temperature region defined by lines AA'K in case of using a solvent having a pressure dependent characteristic of eutectic temperature as shown by the line AA' for example. Accordingly, it is assumed that the temperatures in the upper end portion and in the lower end portion of the solvent in each chamber in Fig. 1 are represented as  $t_1$  and  $t_2$  or  $t_3$  and  $t_4$ , for example. In this

case, if the solvent 13a having an eutectic temperature on the line AA' is used in the upper chamber and the solvent 13b having an eutectic temperature on the line BB' lower than the temperature on the line AA' is used in the lower chamber, crystals of cBN can be synthesized in both of the chambers. It goes without saying that if the solvent having the eutectic temperature on the line AA' is used in the lower chamber, cBN cannot be synthesized.

Fig. 5 shows a further developed arrangement in a synthesizing vessel in accordance with the present invention. In this example, the whole body of the synthesizing vessel has a temperature gradient in a specified direction so that the temperature in the effectively utilizable synthesizing vessel can be decreased in the direction from a top portion of the vessel to a bottom portion thereof as shown in Fig. 5. In order to make the synthesizing vessel have such a temperature gradient, there are provided a disk-shaped heater 28 on the top portion of the cylindrical heater 24 and a heater 29 having a small sectional area in contact therewith. By this arrangement of the heaters, the upper portion of the synthesizing vessel can be more sufficiently heated as compared with the lower portion thereof so that the temperature gradient shown in Fig. 5 can be given. The synthesizing vessel is divided into four chambers 20a, 20b, 20c and 20d and BN sources 22a to 22d, solvents 23a to 23d and seed crystals 21a to 26d are placed in this order in those chambers 20a to 20d, respectively. If the thicknesses of the seed beds 26a to 26c as the partition layers or the thicknesses of the solvents 23a to 23d are selected appropriately, crystals of cBN can be synthesized at a time in the four chambers 20a to 20d of the vessel by using a temperature difference method with four kinds of solvents having different eutectic temperatures AA', BB', CC' and DD' as shown in Fig. 4 being used in the respective chambers. In this manner, the whole body of the synthesizing vessel can be effectively utilized and a large number of large-sized crystals of cBN can be synthesized at a time. Particularly, if a synthesizing apparatus is made to have a large size to increase the size of a synthesizing vessel, the conventional method can only utilize one chamber of the vessel to cause an increase of the proportion of useless space and thus the conventional method is not preferred from an economical point of view. By contrast, a method of the present invention makes it possible to effectively utilize a large-sized synthesizing vessel and as a result cBN can be synthesized at a considerably reduced cost.

Although the plurality of divided chambers were arranged vertically in any synthesizing vessel shown in Figs. 1 and 5, such vertical arrangement of the chambers is not necessarily needed. For example, if a plurality of chambers are arranged radially in a synthesizing vessel so as to give a temperature gradient along the radial direction, crystals of cBN can also be synthesized in the thus arranged chambers.

Solvents to be used in the present invention may be solvents used for the conventional method of

synthesizing cBN. However, in order to obtain crystals of good quality having high purity, it is preferable to use, as solvents, boric nitrides of alkaline metal or alkaline earth metal such as  $\text{Li}_3\text{BN}_2$ ,  $\text{Mg}_3\text{B}_2\text{N}_4$ ,  $\text{Ca}_3\text{B}_2\text{N}_4$ . Those solvents have different eutectic temperatures with respect to hBN. Suitable solvents may be selected among those according to the temperature gradient of the synthesizing vessel.

Furthermore, a suitable additive may be added to one of the above stated boric nitrides of alkaline metal or alkaline earth metal, or two or more kinds of the above stated boric nitrides may be mixed at a suitable ratio, whereby an eutectic compound or the like is produced, causing change in the eutectic temperature with respect to hBN. By making use of this, a solvent having a desired eutectic temperature may be prepared so as to be used for application of the present invention.

It was ascertained by the experiments conducted by the inventors of the present application that crystals of cBN of high quality can be obtained more preferably by using as the solvents a mixture of one or more borates of alkaline metal or alkaline earth metal, at least either  $\text{Li}_3\text{N}$  or  $\text{Li}_3\text{BN}_2$ , and at least one of  $\text{Sr}_3\text{N}_2$ ,  $\text{Ba}_3\text{N}_2$ ,  $\text{Sr}_3\text{B}_2\text{N}_4$  and  $\text{Ba}_3\text{B}_2\text{N}_4$ . It is most preferable to use a solvent containing at least either  $\text{Li}_3\text{N}$  or  $\text{Li}_3\text{BN}_2$  in 1 to 10 wt%, and also containing in 5 to 30 wt% at least one selected from the group consisting of  $\text{Sr}_2\text{N}_2$ ,  $\text{Ba}_3\text{N}_2$ ,  $\text{Sr}_3\text{B}_2\text{N}_4$  and  $\text{Ba}_3\text{B}_2\text{N}_4$ , the remaining part being one or more borates of alkaline metal or alkaline earth metal, whereby large-sized crystals of cBN of high quality can be obtained.

In addition, for the purpose of preventing seed crystals from dissolving in the solvent, hBN of 0.5 to 1 mol% may be added to the above stated solvent, although the effect depends on the composition of the solvent. Particularly, this purpose can be attained effectively in case of adding the above indicated amount of hBN to a solvent only containing a boric nitride of alkaline metal or alkaline earth metal.

Instead of the above stated boric nitrides of alkaline metal or alkaline earth metal, alkaline metals or alkaline earth metals such as Li, Mg, Ca or Sr, or nitrides of alkaline metal or alkaline earth metal such as  $\text{Li}_3\text{N}_2$ ,  $\text{Mg}_3\text{N}_2$ ,  $\text{Ca}_3\text{N}_2$  or  $\text{Sr}_3\text{N}$  may be used as solvents. However, the quality and purity of cBN crystal obtained in these cases tend to be a little deteriorated compared with the case using boric nitrides.

Instead of the above stated solvents of the alkaline metal system or the alkaline earth metal system, solvents containing aluminum alloys such as Ni—Al alloy, Co—Al alloy, Mn—Al alloy, Fe—Al alloy and Si—Al alloy may be used. In these cases, the eutectic temperature with respect to hBN can be changed by changing a ratio of composition of such alloys. Consequently, a suitable ratio of alloy composition can be determined according to the temperature gradient of the synthesizing vessel.

As the BN source in the present invention, cBN powder or hBN powder or a mixture of hBN powder and fine cBN powder or the like may be

used. The seed crystals to be used are small grains of cBN.

A temperature difference in the solvent portion required for application of the present invention is in a range from 10°C to 150°C and preferably in a range from 20°C to 70°C. If the temperature difference is small, the growth rate of cBN is slow and if the temperature difference is too large, crystals of good quality cannot be obtained.

As an apparatus to be used for synthesizing cBN in accordance with the present invention, a belt-type apparatus or a girdle-type apparatus is preferred. However, other ultra-high pressure applying apparatus such as a hexahedron anvil apparatus or an apparatus using a piston and a leader may be used. Pressure and temperature conditions for synthesizing cBN according to the present invention are different dependent on the solvent to be used. In order to synthesize cBN of good quality, the temperature in the low-temperature portion of the solvent suited for growth of cBN is required to be 125°C or more and the pressure in that portion needs to be 40 kbar or more.

In order to make the synthesizing vessel of the present invention have a temperature gradient in a specified direction, various methods may be adopted. Instead of the use of the structure of the heater shown in Fig. 1 and Fig. 5, a method of changing the sectional shape of the heater 34 as shown in Fig. 6A to increase the temperature in an upper portion, or a method of using different materials for the cylindrical heater 44 divided into multiple portions as shown in Fig. 6B to decrease the specific resistance values of the divided portions 44a, 44b and 44c successively from the upper portion to the lower portion, or a method of combining those methods may be used.

When the temperature of the solvent portion at the time of synthesizing cBN is increased and the solvent in a portion contacting the seed crystals begins to dissolve, it may happen that seed crystals dissolve and disappear in the solvent. In such a case, nucleation of cBN occurs spontaneously during synthesis and desired large-sized single crystals of cBN cannot be obtained.

This problem can be solved by dissolving BN in advance in the solvent. BN in the solvent is preferably in a saturated state and thus cBN single crystals of high quality can be obtained.

Alternatively, the solvent and hBN may be mixed to be in a nearly saturated state and in this case, the same effect as described above can also be obtained.

In the following, the present invention will be more specifically described in connection with examples.

#### Example 1

The structure of a synthesizing vessel as shown in Fig. 1 was used.

As the solvents 13a and 13b, a pressed disk of  $\text{Ca}_3\text{B}_2\text{N}_4$  was used in the upper chamber and a pressed disk of  $\text{Ba}_3\text{B}_2\text{N}_4$  was used in the lower chamber. Each of the pressed disks of the

solvents had a diameter of 12 mm and a thickness of 5 mm. As the BN sources 12a and 12b, pressed disks each containing a mixture of cBN powder and hBN powder at a ratio of 1:1 in weight were used. Crystals of cBN having a diameter of about 0.7 mm were used as the seed crystals 1 and they were placed by using platinum seed beds 16a and 16b so as to be in contact with the bottom surface of the solvent of each chamber. The number of seed crystals was three in each chamber as is different from Fig. 1. Pyrophyllite was used as a pressure transmitting medium around the outer wall of the graphite heater 14, while a molded hBN as a pressure transmitting medium was put within the graphite heater 14, Mo plates 15 being provided to separate the BN sources and the solvents from the molded hBN.

A girdle-type ultra-high pressure generating apparatus was used and the heater 14 was conducted under pressure of 52 kbar to heat the synthesizing vessel so that the upper surface of the solvent in the upper chamber was heated to a temperature of 1450°C. At that time, it was supposed that the temperature of the lower surface of the solvent in the upper chamber was about 1400°C and the temperature of the upper surface and the lower surface of the solvent in the second chamber were 1380°C and 1300°C, respectively. That heated state was maintained for 30 hours and then the contents were taken out. Thus, three cBN crystals of about 0.05 ct. were obtained in the upper chamber and three cBN crystals of 0.15 ct. were grown in the lower chamber.

#### Example 2

The structure of a synthesizing vessel as shown in Fig. 5 was used.

The disks of solvents 23a to 23d in the respective chambers each had a diameter of 25 mm and a thickness of 6 mm. As the solvents, a pressed disk of  $\text{Li}_3\text{BN}_2$  was used in the uppermost chamber; a pressed disk of mixture of  $\text{Li}_3\text{BN}_2$  and  $\text{Ca}_3\text{B}_2\text{N}_4$  at a ratio of 10:3 was used in the second chamber; a pressed disk of  $\text{Sr}_3\text{B}_2\text{N}_4$  was used in the third chamber; and a pressed disk of  $\text{Ba}_3\text{B}_2\text{N}_4$  was used in the lowermost fourth chamber. As the BN sources 22a to 22d, the pressed disks same as in the embodiment 1 were used. As the seed crystals, seven cBN crystals having a diameter of about 0.7 mm were placed on a platinum seed bed in each chamber in the same manner as in the embodiment 1. Pyrophyllite was used as a pressure transmitting medium around the outer wall of the graphite heater 24 and a shaped body of hBN was put as a pressure transmitting medium within the graphite heater 24, Mo plates 25 being provided to separate the BN sources 22a to 22d and the solvents 23a to 23d from the shaped body of hBN.

A girdle-type ultra-high pressure generating apparatus was used and the heater was conducted under pressure of 55 kbar to heat the synthesizing vessel so that the temperature of the bottom surface of the  $\text{Li}_3\text{BN}_2$  solvent in the uppermost chamber became about 1620°C. At that time,

the temperature of the bottom surface of the  $Ba_3B_2N_4$  solvent in the lowermost fourth chamber was about 1270°C. That state was maintained for 60 hours and then the contents of the vessel were taken out. cBN crystals of about 0.25 ct. were grown from the seed crystals in each chamber and thus 1.7 ct. were obtained in each chamber.

#### Example 3

The synthesizing vessel had the same structure as in the Example 2, except that the solvents used were 50Ni—50Al alloy, 60Ni—40Al alloy, 60Ni—35Al alloy and 70Ni—30Al alloy in the first to fourth chambers, respectively, in the order starting from the uppermost chamber.

Pressure of 55 kbar was applied and heating was made so that the temperature of the bottom surface of the 50Ni—50Al alloy solvent in the uppermost chamber became 1650°C. At that time, the temperature of the bottom surface of the 70Ni—30Al alloy solvent in the fourth chamber was about 1300°C. That state was maintained for 60 hours and then the contents of the vessel were taken out. cBN crystals of 0.15 to 0.25 ct. were grown from the seed crystals in each of the four chambers of the vessel.

In the following, preferred examples using preferred solvents out of the above described solvents will be more specifically described.

#### Example 4

A synthesizing vessel having the same structure as shown in Fig. 1 was used. As the solvents 13a and 13b, a pressed disk of  $3Li_3N-10Sr_3B_2O_6-87Sr_3B_2O_6$  and a pressed disk of  $3Li_3N-10Ba_3B_2O_6-87Ba_3B_2O_6$  were disposed in the upper chamber 10a and the lower chamber 10b, respectively. Each of the pressed disks of the solvents 13a and 13b had a diameter of 12 mm and a thickness of 5 mm. As the BN sources 12a and 12b, pressed disks of a mixture of cBN powder and hBN powder at a ratio of 1:1 in weight were used. As the used crystals 11a and 11b, crystals of cBN having a diameter of about 0.7 mm were used and they were placed in contact with the bottom surfaces of the solvents 13a and 13b in the chambers 10a and 10b, by using platinum seed beds 16a and 16b, respectively. The number of each of the seed crystals 11a and 11b placed in the seed beds 16a and 16b, respectively, was three. Pyrophyllite was provided as a pressure transmitting medium around the outer wall of the graphite heater 14 and a shaped body of hBN was put within the graphite heater 14, molybdenum plates 15 being provided to separate the BN sources 12a and 12b and the solvents 13a and 13b from the shaped body of hBN.

A girdle-type ultra-high pressure generating apparatus was used and the heater 14 was conducted under pressure of 52 kbar to heat the synthesizing vessel so that the upper surface of the solvent 13a in the upper chamber 10a was heated to a temperature of 1650°C. At that time, the temperature of the lower surface of the

solvent 13a was about 1600°C. It was supposed that the temperatures of the upper surface of the lower surface of the solvent 13b in the lower chamber 10b were 1570°C and 1500°C, respectively. That heated state was maintained for 30 hours and then the cBN crystals obtained were taken out. Thus, it was found that three cBN crystals of about 0.1 ct. were grown in the upper chamber 10a and three cBN crystals of about 0.1 ct. were grown in the lower chamber 10b.

#### Example 5

Crystals of cBN were grown by using the same synthesizing vessel as in the Example 4. A different point from the Example 4 is that  $8Li_3BN_2-15Sr_3B_2N_4-77Sr_3B_2O_6$  was used as the solvent 13a in the upper chamber 10a and  $8Li_3BN_2-20Ba_3B_2N_4-72Ba_3B_2O_6$  was used as the solvent 13b in the lower chamber 10b. The other materials were the same as in the embodiment 4.

The synthesizing vessel structured as described above was heated by conducting the heater 14 under pressure of 52 kbar using a girdle-type ultra-high pressure generating apparatus so that the upper surface of the solvent 13a in the upper chamber 10a was heated to a temperature of 1650°C. At that time, it was supposed that the temperature of the lower surface of the solvent 13a was about 1600°C and the temperatures of the upper surface and the lower surface of the solvent 13b in the lower chamber 10b were 1570°C and 1500°C, respectively. That heated state was maintained for 30 hours and then the grown cBN crystals were taken out. As a result, it was found that three cBN crystals of about 0.15 ct. were grown in the upper chamber 10a and three cBN crystals of 0.2 ct. were grown in the lower chamber 10b.

#### Example 6

A synthesizing vessel having the same structure as in the Example 2 was used and  $5Li_3N-15Sr_3B_2N_4-79Sr_3B_2O_6-1hBN$ ,  $5Li_3N-15Sr_3B_2N_4-70Sr_3B_2O_6-9K_2B_4O_7-1hBN$ ,  $3Li_3N-20Ba_3B_2N_4-65Ba_3B_2O_6-11K_2B_4O_7-1hBN$  and  $3Li_3N-20Ba_3B_2N_4-59Ba_3B_2O_6-17Na_2B_4O_7-1hBN$  were used as the solvents in this order from the uppermost chamber to the lowermost chamber.

Pressure of 55 kbar was applied and the synthesizing vessel was heated so that the bottom surface of the solvent 23a of  $5Li_3N-15Sr_3B_2N_4-79Sr_3B_2O_6-1hBN$  in the uppermost chamber was heated to a temperature of 1700°C. At that time, the temperature of the bottom surface of the solvent 23d of  $3Li_3N-20Ba_3B_2N_4-59Ba_3B_2O_6-17Na_2B_4O_7-1hBN$  in the lowermost chamber was about 1370°C. That heated state was maintained for 90 hours and then the grown crystals were taken out. As a result, it was found that cBN crystals of 0.5 to 0.6 ct. were grown from the seed crystals in each of the four chambers 20a to 20d.

Although the present invention has been described and illustrated in detail, it is clearly

understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

### Claims

1. A method of synthesizing crystals of cubic system boron nitride by using boron nitride sources, solvents for dissolving said boron nitride sources and seed crystals under conditions of ultra-high pressure and high temperature for maintaining cubic system boron nitride stable, said method comprising the steps of:

preparing a synthesizing vessel having at least two chambers separated by one or more partition layers not reacting with said solvents, said at least two chambers being arrayed in order in said synthesizing vessel so as to be heated according to a temperature gradient in a specified direction;

placing, in said at least two chambers, said solvents having different eutectic temperatures with respect to said boron nitride sources according to said temperature gradient; placing said boron nitride source in contact with a portion of each of said solvents heated at a relatively higher temperature and placing at least a seed crystal in a portion of each of said solvents heated at a relatively lower temperature; and

growing at least a crystal of cubic system boron nitride in each of said solvents in said chambers by heating said synthesizing vessel with said temperature gradient under conditions of ultra-high pressure and high temperature.

2. A method of synthesizing crystals of cubic system boron nitride as defined in claim 1, wherein said temperature gradient is applied in a manner in which temperature is increased from one end of an array of said chambers to the other end of said array.

3. A method of synthesizing crystals of cubic system boron nitride as defined in claim 1, wherein said chambers are arrayed in a radial direction and said temperature gradient is applied in said radial direction.

4. A method of synthesizing crystals of cubic system boron nitride as defined in claim 2, wherein said chambers are arrayed in a vertical direction and said temperature gradient is applied to said chambers in said vertical direction.

5. A method of synthesizing crystals of cubic system boron nitride as defined in claim 1, wherein a heater is provided around an outer wall of said synthesizing vessel so that said synthesizing vessel is heated with said temperature gradient.

6. A method of synthesizing crystals of cubic system boron nitride as defined in claim 1, wherein pressure of 40 kbar or more is applied to grow said crystals of cubic system boron nitride, and the lowest temperature portion of the solvent in the chamber heated at the lowest temperature out of the chambers of said synthesizing vessel is heated to 1000°C or more.

7. A method of synthesizing crystals of cubic system boron nitride as defined in claim 1, wherein a mixture containing at least one of borates of alkaline metal or alkaline earth metal, at least either  $\text{Li}_3\text{N}$  or  $\text{Li}_3\text{BN}_2$  and at least one of  $\text{Sr}_3\text{N}_2$ ,  $\text{Ba}_3\text{N}_2$ ,  $\text{Sr}_3\text{B}_2\text{N}_4$  and  $\text{Ba}_3\text{B}_2\text{N}_4$  is used for said solvents.

8. A method of synthesizing crystals of cubic system boron nitride as defined in claim 7, wherein a solvent containing at least either  $\text{Li}_3\text{N}$  or  $\text{Li}_3\text{BN}_2$  in 1 to 10 wt%, at least one selected from the group consisting of  $\text{Sr}_3\text{N}_2$ ,  $\text{Ba}_3\text{N}_2$ ,  $\text{Sr}_3\text{B}_2\text{N}_4$  and  $\text{Ba}_3\text{B}_2\text{N}_4$ , in 5 to 30 wt% and at least one of borates of alkaline metal or alkaline earth metal as the remaining part is used for said solvents.

### Patentansprüche

1. Verfahren zur Synthese von Bornitrid des kubischen Systems durch Verwendung von Bornitrid-Quellen, Lösungsmitteln zum Lösen der Bornitrid-Quellen und von Impfkristallen unter Ultrahochdruck- und Hochtemperaturbedingungen, um das Bornitrid des kubischen Systems stabil zu halten, wobei das Verfahren folgende Schritte aufweist:

Bereitstellen eines Synthese-Gefäßes mit wenigstens zwei Kammern, die durch eine oder mehrere nicht mit den Lösungsmitteln reagierenden Teilungsschichten abgeteilt sind, wobei die wenigstens zwei Kammern in dem Synthesiergefäß in regelmäßiger Anordnung so angeordnet sind, daß sie gemäß einem Temperaturverlauf in einer bestimmten Richtung erwärmt werden;

Einbringen der Lösungsmittel, die gemäß dem Temperaturverlauf bezüglich der Bornitrid-Quellen unterschiedliche eutektische Temperaturen aufweisen, in die wenigstens zwei Kammern; in Kontakt Bringen der Bornitrid-Quelle mit einem Teil jedes der Lösungsmittel, die auf eine relativ höhere Temperatur erwärmt sind und Einbringen von wenigstens einem Impfkristall in einen Teil jedes Lösungsmittel, die auf einer relativ niedrigeren Temperatur erwärmt sind; und

Züchten von wenigstens einem Bornitridkristall des kubischen Systems in jedem Lösungsmittel in den Kammern durch Erwärmen des Synthese-Gefäßes mit dem Temperaturverlauf unter Ultrahochdruck- und Hochtemperaturbedingungen.

2. Verfahren zur Synthese von Bornitrid des kubischen Systems nach Anspruch 1, dadurch gekennzeichnet, daß der Temperaturverlauf derart angewendet wird, daß die Temperatur von einem Ende der Anordnung der Kammern zum anderen Ende der Anordnung gesteigert wird.

3. Verfahren zur Synthese von Bornitrid des kubischen Systems nach Anspruch 1, dadurch gekennzeichnet, daß die Kammern in einer radialen Richtung ausgerichtet angeordnet sind und der Temperaturverlauf in dieser radialen Richtung angewendet wird.

4. Verfahren zur Synthese von Bornitrid des kubischen Systems nach Anspruch 2, dadurch gekennzeichnet, daß die Kammern in einer verti-

kalen Richtung ausgerichtet angeordnet sind und der Temperaturverlauf auf die Kammern in dieser vertikalen Richtung angewendet wird.

5. Verfahren zur Synthese von Bornitrid des kubischen Systems nach Anspruch 1, dadurch gekennzeichnet, daß um eine äußere Wand des Synthesiergefäßes herum eine Heizvorrichtung vorgesehen ist, so daß das Synthese-Gefäß mit dem Temperaturverlauf erwärmt wird.

6. Verfahren zur Synthese von Bornitrid des kubischen Systems nach Anspruch 1, dadurch gekennzeichnet, daß

ein Druck von 40 kbar oder mehr angewendet wird, um die Bornitridkristalle des kubischen Systems zu züchten, und

der niedrigste Temperaturteil des Lösungsmittels in der Kammer, die von den Kammern des Synthese-Gefäßes auf die niedrigste Temperatur erwärmt ist, auf 1000°C oder mehr erwärmt wird.

7. Verfahren zur Synthese von Bornitrid des kubischen Systems nach Anspruch 1, dadurch gekennzeichnet, daß eine Mischung, die wenigstens eines der Borate von Alkalimetallen oder Erdalkalimetallen, wenigstens entweder  $\text{Li}_3\text{N}$  oder  $\text{Li}_3\text{BN}_2$  und wenigstens eines von  $\text{Sr}_3\text{N}_2$ ,  $\text{Ba}_3\text{N}_2$ ,  $\text{Sr}_3\text{B}_2\text{N}_4$  und  $\text{Ba}_3\text{B}_2\text{N}_4$  aufweist, für die Lösungsmittel verwendet wird.

8. Verfahren zur Synthese von Bornitrid des kubischen Systems nach Anspruch 7, dadurch gekennzeichnet, daß ein Lösungsmittel, das wenigstens entweder  $\text{Li}_3\text{N}$  oder  $\text{Li}_3\text{BN}_2$  in 1 bis 10 Gewichts-%, wenigstens eines aus des Gruppe, bestehend aus  $\text{Sr}_3\text{N}_2$ ,  $\text{Ba}_3\text{N}_2$ ,  $\text{Sr}_3\text{B}_2\text{N}_4$  und  $\text{Ba}_3\text{B}_2\text{N}_4$ , in 5 bis 30 Gewichts-% und wenigstens eines der Borate von Alkalimetall oder Erdalkalimetall als Rest enthält, für die Lösungsmittel verwendet wird.

## Revendications

1. Un procédé de synthèse de cristaux de nitrure de bore du système cubique en utilisant des sources de nitrure de bore, des solvants pour dissoudre ces sources de nitrure de Bore et en ensemençant les cristaux dans des conditions d'ultra haute pression et de hautes températures, pour maintenir stable le nitrure de bore du système cubique, ledit procédé comprenant les étapes de:

préparation d'un récipient à synthétiser ayant au moins deux chambres séparées par une ou plusieurs couches de séparation qui ne réagissent pas avec lesdits solvants, lesdites deux chambres au moins étant disposées en ordre dans ledit récipient à synthétiser, de façon à être chauffées à un gradient de température dans une direction spécifiée

placement dans lesdits deux chambres au moins, desdits solvants ayant des températures eutectiques différentes par rapport auxdites sources de nitrure de bore conformément audit gradient de température

placement de ladite source de nitrure de bore en contact avec une fraction de chacun desdits

solvants chauffés à une température relativement plus élevée et placement d'au moins un cristal d'ensemencement dans une fraction de chacun desdits solvants chauffés à une température relativement plus basse et en laissant grossir au moins un cristal de nitrure de bore du système cubique dans chacun desdits solvants dans lesdites chambres, par chauffage dudit récipient à synthétiser dans ledit gradient de température dans les conditions d'ultra haute pression et de haute température.

2. Un procédé pour synthétiser des cristaux de nitrure de bore du système cubique selon la revendication 1, dans lequel ledit gradient de température est appliqué d'une façon selon laquelle le température est augmentée d'une extrémité d'une rangée desdites chambres à l'autre extrémité de ladite rangée.

3. Un procédé pour synthétiser des cristaux de nitrure de bore du système cubique selon la revendication 2, dans lequel lesdites chambres sont disposées dans une direction radiale et ledit gradient de température est appliqué dans ladite direction radiale.

4. Un procédé pour synthétiser des cristaux de nitrure de bore du système cubique selon la revendication 2, dans lequel lesdites chambres sont disposées dans ladite direction verticale.

5. Un procédé pour synthétiser des cristaux de nitrure de bore du système cubique selon la revendication 1, dans lequel un chauffage est disposé autour d'une paroi extérieure dudit récipient à synthétiser, de sorte que ledit récipient à synthétiser est chauffé selon ledit gradient de température.

6. Un procédé pour synthétiser des cristaux de nitrure de bore du système cubique selon la revendication 1, dans lequel une pression de 40 h bar ou plus, est appliquée pour faire grossir lesdits cristaux de nitrure de bore du système cubique et la fraction à la température la plus basse dans la chambre chauffée à la température la plus basse, en dehors des chambres dudit récipient à synthétiser, est chauffée à 1,000°C ou plus.

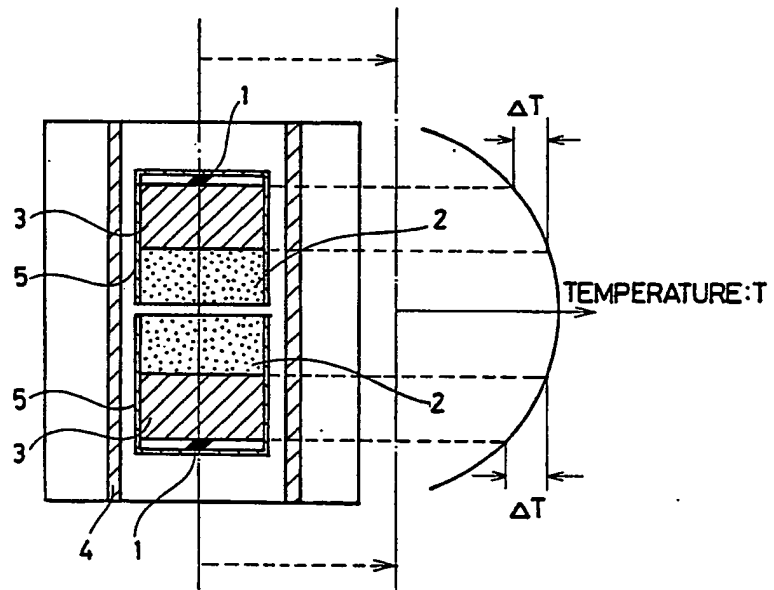
7. Un procédé pour synthétiser des cristaux de nitrure de bore du système cubique selon la revendication 1, dans lequel un mélange contenant au moins un des borates de métal alcalin ou de métal alcalino-terreux, au moins  $\text{Li}_3\text{N}$  ou  $\text{Li}_3\text{BN}_2$  et au moins un dérivé choisi parmi  $\text{Sr}_3\text{N}_2$ ,  $\text{Ba}_3\text{N}_2$ ,  $\text{Sr}_3\text{B}_2\text{N}_4$  et  $\text{Ba}_3\text{B}_2\text{N}_4$ , est employé pour lesdits solvants.

8. Un procédé pour synthétiser des cristaux de nitrure de Bore du système cubique selon la revendication 7, dans lequel un solvant contenant au moins  $\text{Li}_3\text{N}$  ou  $\text{Li}_3\text{BN}_2$  à raison de 1 à 10% en poids, au moins un composé choisi dans le groupe constitué par  $\text{Sr}_3\text{N}_2$ ,  $\text{Ba}_3\text{N}_2$ ,  $\text{Sr}_3\text{B}_2\text{N}_4$  et  $\text{Ba}_3\text{B}_2\text{N}_4$ , à raison de 5 à 30% en poids et au moins un des borates de métal alcalin ou de métal alcalino-terreux en tant que part résiduelle, est utilisé pour lesdits solvants.





FIG.3



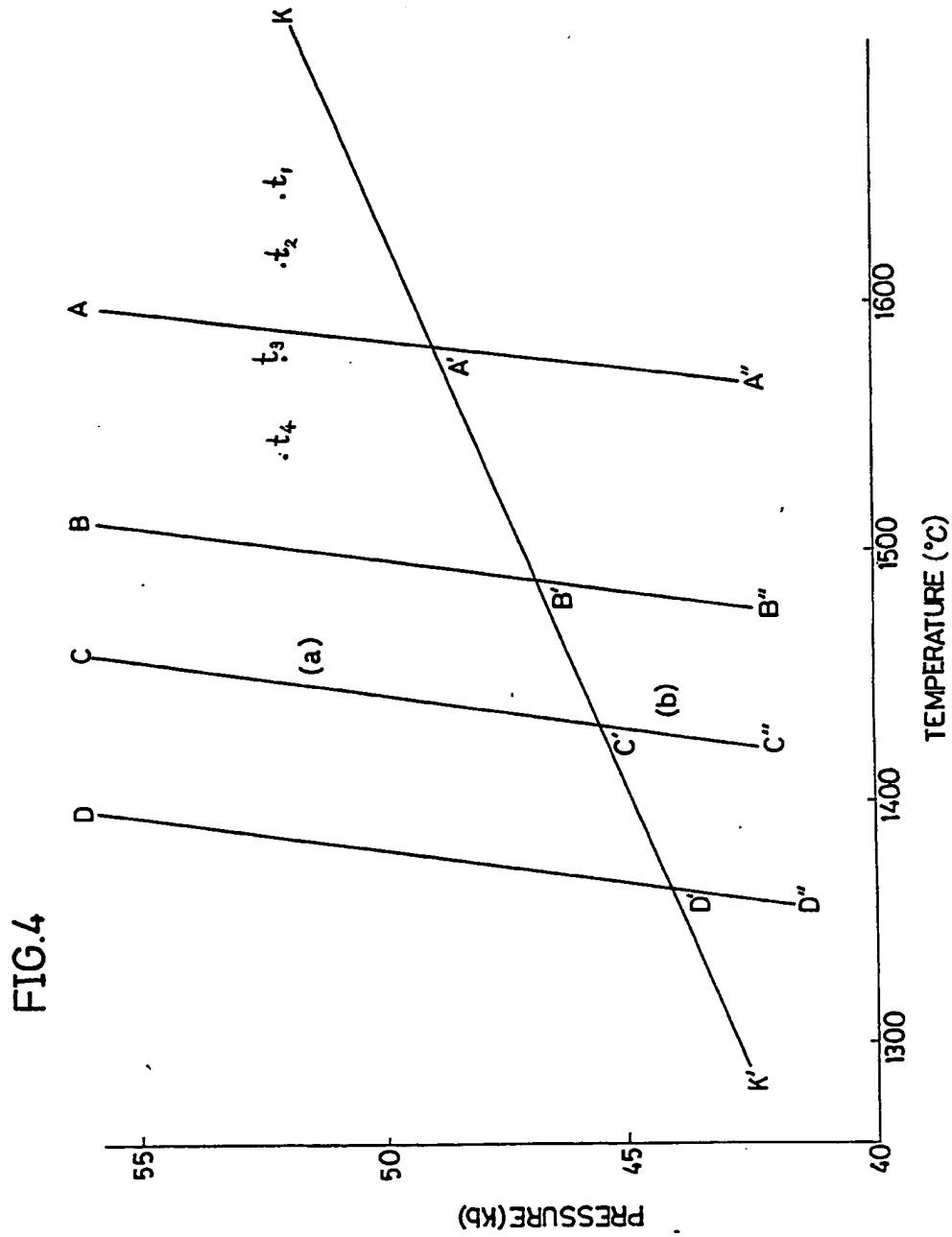


FIG.5

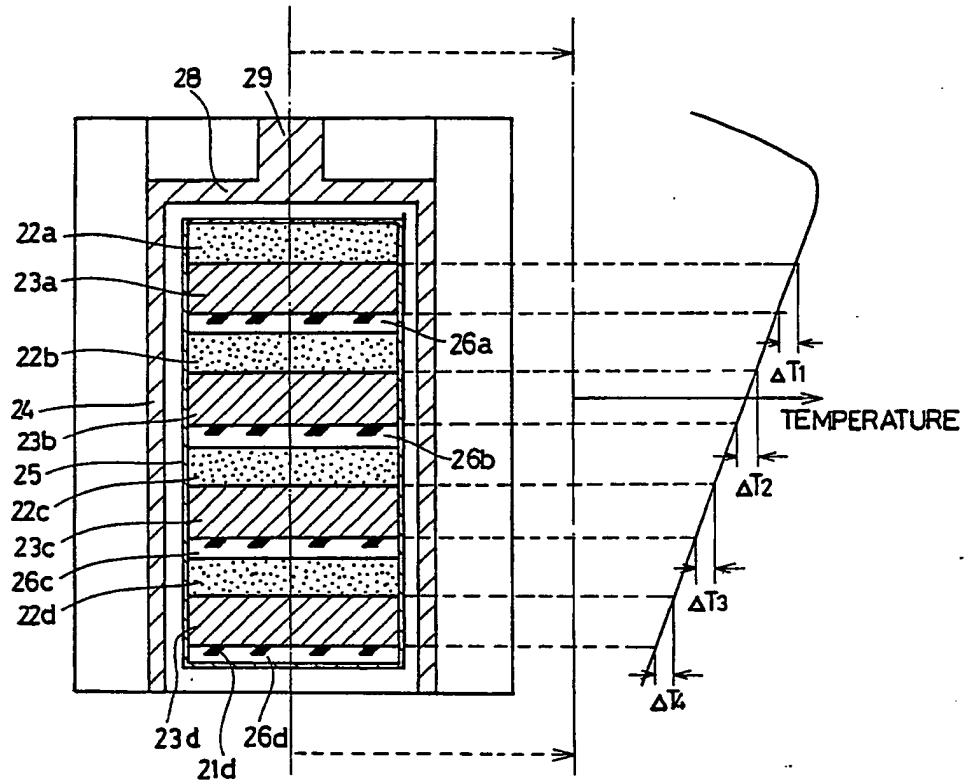


FIG.6A

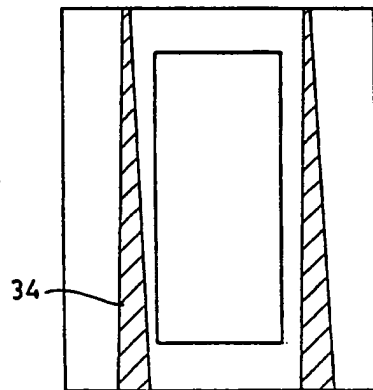


FIG.6B

